POWER DISTRIBUTION

FOR

HIGH-RELIABILITY QUADRUPLE-DIVERSITY COMMUNICATIONS SYSTEMS

FEBRUARY 1963

JACKSON & MORELAND, INC.

ESD-TDR-64-412

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JACKSON & MORELAND, INC.

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Boston, February 8, 1963

Mr. J. J. Gano
J. J. Gano & Associates
2225 Massachusetts Avenue
Cambridge Massachusetts

Dear Mr. Gano:

We submit herewith the report "Power Distribution for High-reliability Quadruple-diversity Communications Systems."

This report reflects the revisions and redrafting called for by the client's representative. Section 7.0, prepared by the client, has been added as an extension of the basic work.

Very truly yours,

JACKSON & MORELAND, INC.

By A E Fitzgerald
A. E. Fitzgerald

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1.0 PURPOSE

The object of this ~~study~~ Report is to make recommendations for a conceptual power distribution layout suitable for high-reliability quadruple-diversity communication system stations having a six engine-generator, double-bus, primary power plant.

2.0 SCOPE OF STUDY

The general definition and broad outline of the power distribution system are presented in the Bell Telephone Laboratories specification "Power Generation and Distribution Engineering Requirements" dated 29 September 1958. By direction, the "no-break" power portion of the Bell Laboratories specification is outside of the scope. The conceptual design of the distribution system, herein presented, is based upon the loads, generating units, and availability requirements as defined in a companion report by Jackson & Moreland, Inc., "Power Generation for High-Reliability Quadruple-Diversity Communications Systems" dated January 1963. Reliability requirements for the power-distribution system are stated in Section 4.0 herein.

Possible malfunctioning of power distribution equipment is reflected qualitatively on the basis of engineering practice and operating experience with comparable installations.

3.0 SUMMARY OF CONCLUSIONS

As a result of these studies, the distribution system shown in Figure 1, on the next page, is recommended for the double-bus, six-generator plant. The principal features are:

(1) Two generators manually transferable between busses.

(2) Two non-transferable generators per bus.

(3) Technical and Interruptible Electronics loads manually transferable between busses.

(4) Half the Utility load connected to each bus and not transferable between busses.

(5) Interruptible Electronics and Utility loads on either bus shed automatically upon loss of an operating generator on that bus.

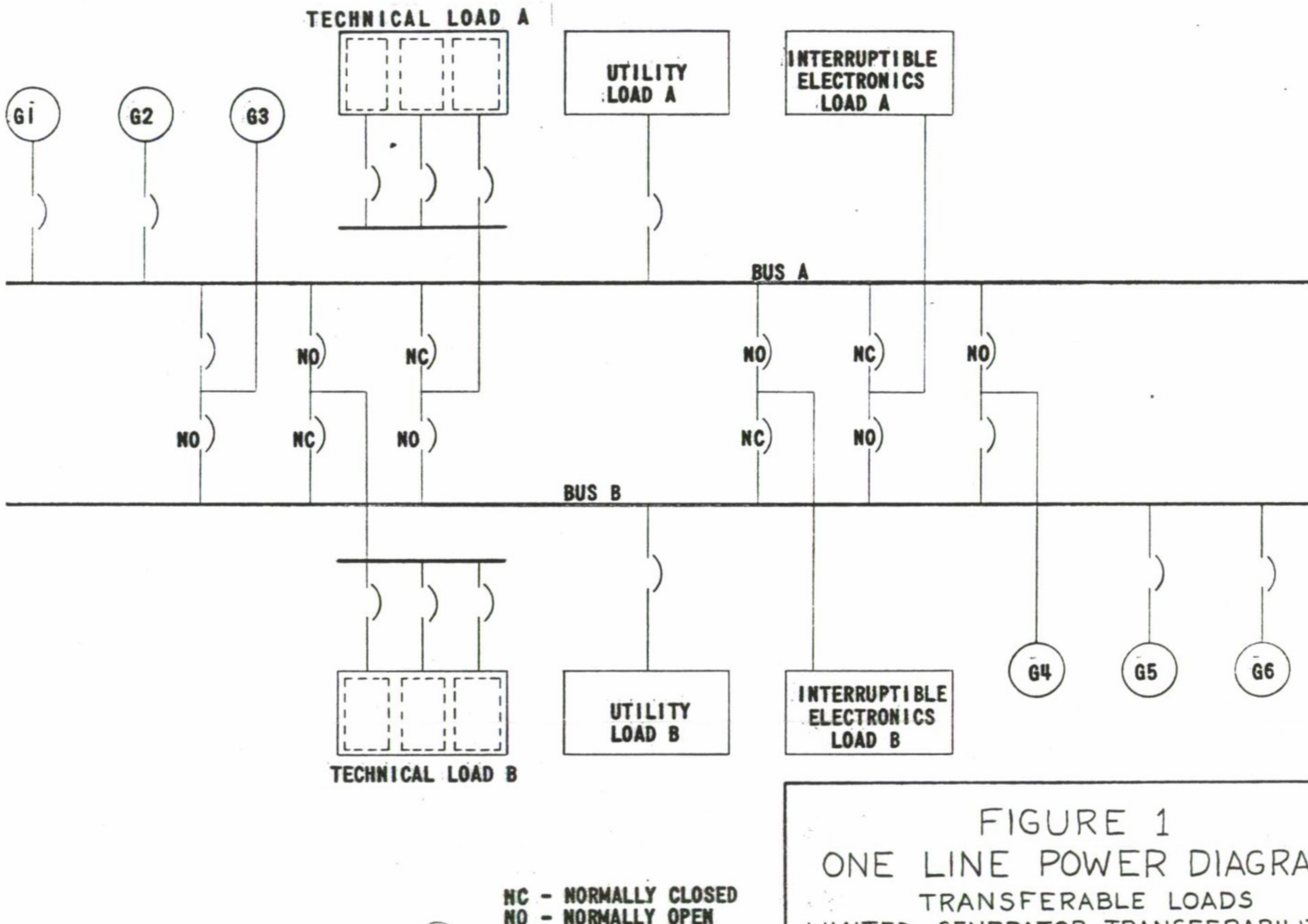


FIGURE 1
ONE LINE POWER DIAGRAM
TRANSFERABLE LOADS
LIMITED GENERATOR TRANSFERABILITY

4.0 RELIABILITY REQUIREMENTS FOR POWER DISTRIBUTION

The following are the requirements for the power distribution system to have a reliability compatible with that of the primary power plant and the quadruple-diversity communications system:

(1) The power distribution system should be designed for an availability consistent with that of the power-generating and load equipments.

(2) Faults or disturbances in the generator busses and distribution circuits should not cause simultaneous shutdown of two dual-diversity units performing a quadruple-diversity function.

(3) The effect and frequency of occurrence of serious power outages and disturbances which impair the performance of the loads should be minimized.

5.0 POWER DISTURBANCES - DESIGN BACKGROUND

In general terms, the power supply to the several load elements in a station is subject to two types of disturbances. The first, a transient disturbance, appears in the form of a voltage dip, with or without a short-term departure from the specified operating frequency. The second is a power outage, characterized by complete interruption of power to at least one load element. Almost all of these disturbances or power outages are caused by short circuits (usually to ground) in the generators, distribution circuits or loads themselves.

With modern protective and control equipment, transient disturbances will be of very brief duration - less than 0.75 second.

Because of their brevity, such disturbances will cause only temporary impairment of the communications system, and no erroneous information will persist. The magnitude of the disturbance will be a function of the location of the fault and the number of phases involved. A significant proportion will be sufficiently minor so that they will be filtered by the power rectification section of the electronic system and will not affect performance.

A certain number of power outages to elements of the load will be inevitable. For example, the process of clearing a short circuit to ground on a distribution feeder necessarily involves interruption of the loads supplied by that feeder. The duration of this outage will be determined by the time required to locate the fault and repair or replace the feeder.

In some typical communication equipments, power outages of 0.75 second and longer are undesirable because it is necessary to initiate restart and/or recycling procedures. These procedures may necessitate 15 to 30 minutes to achieve the desired operating level or efficiency. For this typical equipment, one outage (during a year) of 15 to 30 minutes might be intolerable whereas 10 or even 100 disturbances, each less 0.75 second, might be within operating specifications of the communication systems.

6.0 CONCEPTUAL LAYOUT OF ELECTRIC BUS AND DISTRIBUTION SYSTEM

The basic bus and distribution-system configurations which have been considered are shown in Figures 1, 2, and 3, on pages 3 , 14, and 15. The basic design principle of the bus layouts is to provide the required degree of power availability and operating flexibility with the minimum number of distribution system components. The general engineering practices of providing one degree of back-up protection and an alternate means of operation with any one component out of service are compatible with these criteria and are applied here.

The three configurations of Figures 1, 2, and 3 use a double or split-bus arrangement and six engine generators as recommended in the companion report. The significant differences among the three configurations reside in the transferability of the generators between busses, the transferability of loads, the use of tie breaker between the busses, and the use of sub-busses. In the systems of Figures 1 and 2, only two of the six generators can be connected to either bus. The system of Figure 1 has the first and second priority loads transferable between busses, whereas that of Figure 2 has no transferability of loads, but does employ a tie breaker between busses. In the system of Figure 3, all six generators and the first and second priority loads can be connected to either bus.

A detailed description of the three types of loads is presented in the companion report. They are, in order of priority:

(1) Non-Interruptible or Technical Load (quadruple-diversity communications)

(2) Short-Term Interruptible Electronics

(3) Utility

The features of each of the systems are discussed in the following sections.

6.1 CONFIGURATION 1: TRANSFERABLE LOADS AND LIMITED GENERATOR TRANSFERABILITY

The recommended configuration of Figure 1, on page 3, possesses the required degree of flexibility and power availability and is intermediate to the other two systems on the basis of complexity.

6.1.1 DOUBLE BUS

The double-bus arrangement provides duplicate isolated power sources and thereby confines disturbances to half the total load. Such confinement assures continuous service to at least one section of the highest priority load, the dual-diversity communication load, and thereby improves chances for uninterrupted communication.

6.1.2 TRANSFERABILITY OF LOADS

The Technical and Short-Term Interruptible loads may be transferred from one bus to the other by means of an interlocked pair of circuit breakers. With this feature of flexibility, the entire quadruple-diversity communication system and possibly the second and third priority loads can be carried, depending upon the number of generators available, in the event of a major bus fault. Although rare in occurrence (a probability of once in the life of a plant in the average) failure of a bus or a switchgear component may involve flashover or fire within the metalclad switchgear. This may result in a prolonged outage of a bus, particularly in remote installations where spare parts and skilled manpower are not readily available. The double-breaker supply overcomes the problem of such a prolonged outage.

The time necessary to transfer the technical loads does not significantly affect the overall availability of the communication system because the probability that a transfer will be required is so low. Therefore, a manual transfer of the Technical load is recommended. An automatic transfer, within 0.75 second, appears to have the advantage of maintaining both of the dual-diversity systems in continuous operation in the event of a bus fault. However, an automatic transfer may expose the unaffected bus to faults on the other bus. In addition, an automatic transfer may impose an overload on the remaining generators. Either of these conditions would result in the serious situation of complete breakdown of the communication system. With manual transfer, one of the dual diversity units will be without power for the time it takes an operator to isolate the fault and perform the switching, usually less than fifteen minutes. The transferred communication system will not be at a high operational efficiency for possibly another fifteen minutes, but the other section of the communication system is assured of continuous operation.

The manual transfer has the further advantage of simpler control equipment which increases reliability and reduces costs.

By inference from its name, the Short-Term-Interruptible load has even less need for an automatic transfer arrangement. For the Utility load, which is divided approximately equally between the two busses, a single breaker for each half is considered adequate.

6.1.3 LOAD SHEDDING

The quadruple-diversity communication load requires continuous power at all times even at the expense of interrupting the lower

priority loads. Thus, in the event of a generator failure on one bus, the Short-Term Interruptible and Utility loads on the bus should be dropped by automatically opening the appropriate circuit breakers. A standby generator can then be connected to the bus and the interrupted loads re-energized.

6.1.4 DISTRIBUTION TO LOADS

In Figure 1 the three types of loads are represented by blocks. There are two blocks for the Technical load, one for each dual-diversity unit. The Short-Term Interruptible load is also divided into two blocks, one for each bus, and the Utility load is treated similarly.

Within each Technical load block there are several segments of associated loads. For the dual-diversity communication unit, the loss of any one segment may result in the breakdown of the whole unit. All segments of a block are fed from a single distribution sub-bus via separate distribution breakers. The design of the several sub-busses can be implemented in the form of several local load centers or one centrally-located switchboard. The sub-busses are in turn connected to the generator busses through interlocked pairs of circuit breakers.

In contrast to the arrangement of a pair of interlocked circuit breakers and a sub-bus for each of the dual-diversity units, an arrangement which employs a pair of interlocked circuit breakers for each segment of the Technical load could be employed, as shown in Figure 3. The configuration of Figure 1 is recommended because fewer main circuit breakers are required and plant availability is increased by the back-up protection offered at the main breakers. In addition, the reliability of the transfer of the Technical load is increased with only a minimum of two breakers operating during a transfer.

6.1.5 GENERATOR TRANSFERABILITY

As shown in the six-engine-generator, double-bus system of Figure 1, two generators are connected only to Bus A, two only to Bus B, and two can be connected to either bus through pairs of interlocked circuit breakers. This arrangement provides that, with any two of the six generators out of service, two generators will still be available to each bus. Also, with either bus out of service, up to four generators may be available to the remaining bus.

Two generators normally operate on each bus with two idle spares for either bus. Upon loss of one running generator, the interruptible loads on the associated bus are automatically shed. A spare generator is started and connected manually, and the interruptible load feeders are then reclosed.

Proper operating and maintenance schedules will keep to a minimum the number of cases (approximately three times per year on the average) where extra switching operations are required because only two generators are transferable between busses. This possible extra switching is completely avoided if all six units are switchable to either bus, as shown in Figure 3, but the additional cost and complexity, which does not increase the power plant reliability, is not justified.

The following examples will serve to illustrate the concepts of proper operating and maintenance schedules for the configuration of Figure 1. Generators 1, 2, and 3 should be operated in association with Bus A, and generators 4, 5, and 6 with Bus B. In this way, the two transferable units (3 and 4) will not be required to operate on the same bus at the same time, and one spare unit is normally available to each bus

to cover failure of a running unit. Whenever a transferable generating unit is taken out for maintenance, the other transferable unit, if running, should be replaced by a non-transferable unit so that the one remaining spare unit can be directly connected to either bus. In the rare event that only three generators are available, a predetermined allocation of loads between the busses will enable the installation to be operated with all the Technical load and much, if not all, of the remaining load.

6.1.6 PHYSICAL ARRANGEMENT OF SWITCHGEAR

With a double-bus layout, two basic switchgear configurations are possible:

(a) One unit of switchgear containing both main busses.

(b) Two units of switchgear, each containing one main bus, located in close proximity and with interconnecting power and control cables for every circuit.

The second alternative offers a higher degree of physical isolation for the power supply equipment than the first, but this advantage is offset by the lower reliability resulting from the interconnecting cables and control wiring.

6.2 CONFIGURATION 2: NON-TRANSFERABLE LOADS AND LIMITED GENERATOR TRANSFERABILITY

The single split bus configuration of Figure 2 on page 14 was also considered. The differences from that of Configuration 1 are:

(1) None of the loads are transferable between busses.

(2) A normally-open tie breaker is inserted between the busses.

The characteristics of generator transferability, load shedding, and distribution to the loads are identical to those of Configuration 1.

The significant features of the single split bus configuration are lower cost and simplified operation, but less flexibility. Inasmuch as the generator arrangement is the same, the power supply to the main busses has equal flexibility and availability. However, the inability to transfer loads has the disadvantage, that, in the event of a serious bus fault, there may be prolonged power outage of half the total load (including one dual-diversity half of the communications system).

6.2.1 PHYSICAL ARRANGEMENT OF SWITCHGEAR

The following two switchgear arrangements for the split bus are comparable to those of the double bus:

(a) One unit with a fireproof barrier isolating the two sections.

(b) Two separated units connected by bus duct and a minimum of cable circuits.

A higher degree of isolation of the power supply equipment for the dual-diversity units, with increased reliability, can be obtained with the single split bus. However, the more flexible double-bus arrangement with the ability to transfer loads is more compatible with the overall reliability requirements and operating characteristics of these quadruple-diversity communication centers.

6.2.2 BUS-TIE BREAKER

In the event only three generators are available, nearly full load operation can be realized by manually closing the bus-tie breaker. This procedure contradicts the philosophy of confining any given disturbance to half the load.

With the ability to transfer loads in the double bus of Configuration 1, a bus-tie breaker would not appreciably increase flexibility, and the reduced reliability resulting from an inadvertent closure, offsets this advantage.

6.3 CONFIGURATION 3: ALL GENERATORS TRANSFERABLE

This configuration, shown in Figure 3 on page 15, has all six generators transferable to either bus. The increased flexibility is accompanied by additional cost and complexity which are not justifiable. The system of Figure 1 with only two generators transferable offers sufficient flexibility if proper operating and maintenance procedures as discussed in Section 6.1.5 are followed.

Each segment of the Technical load is supplied through interlocked circuit breakers connected at the main bus. The disadvantage of using the large number of breakers is discussed in Section 6.1.4.

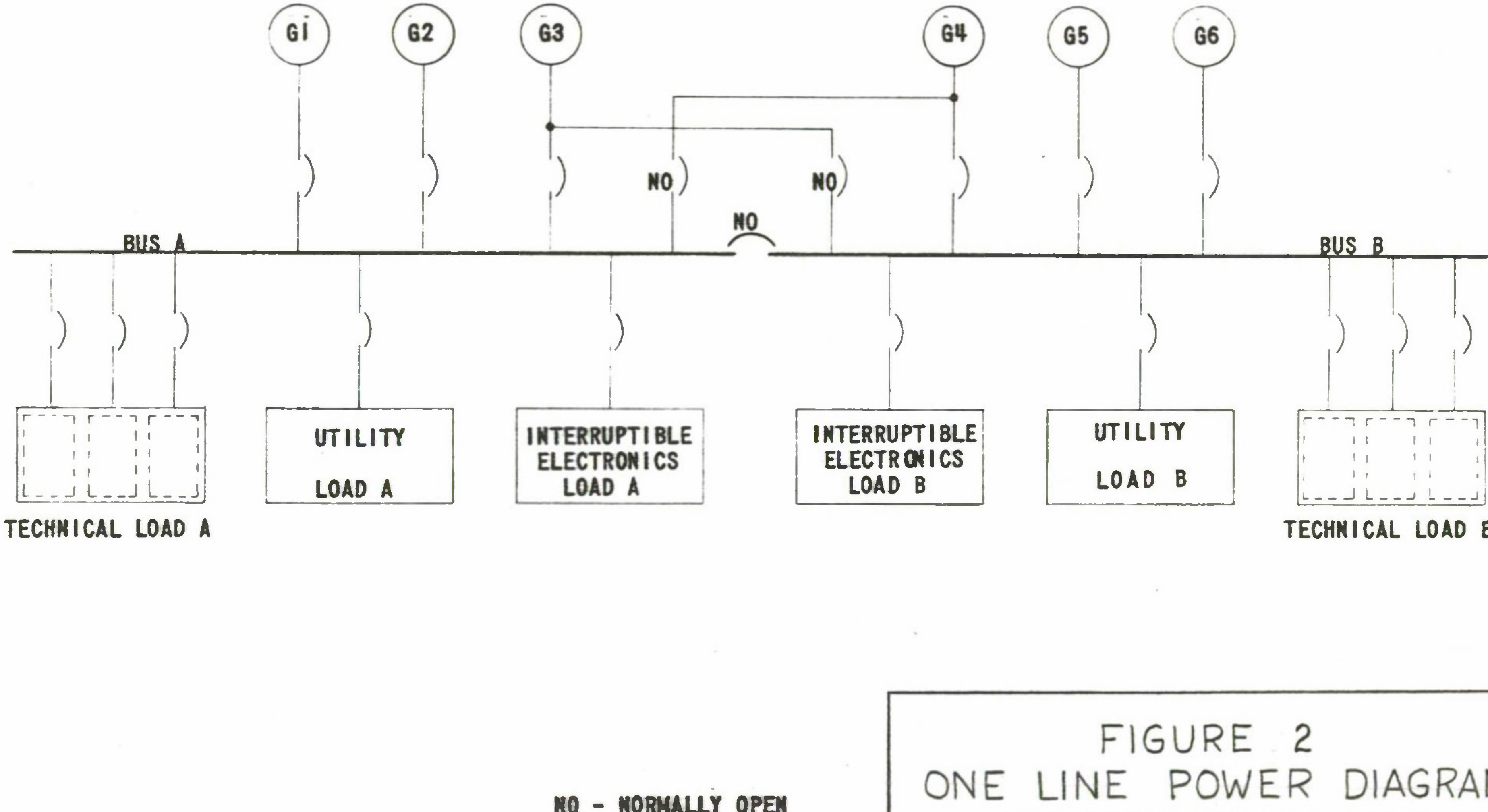
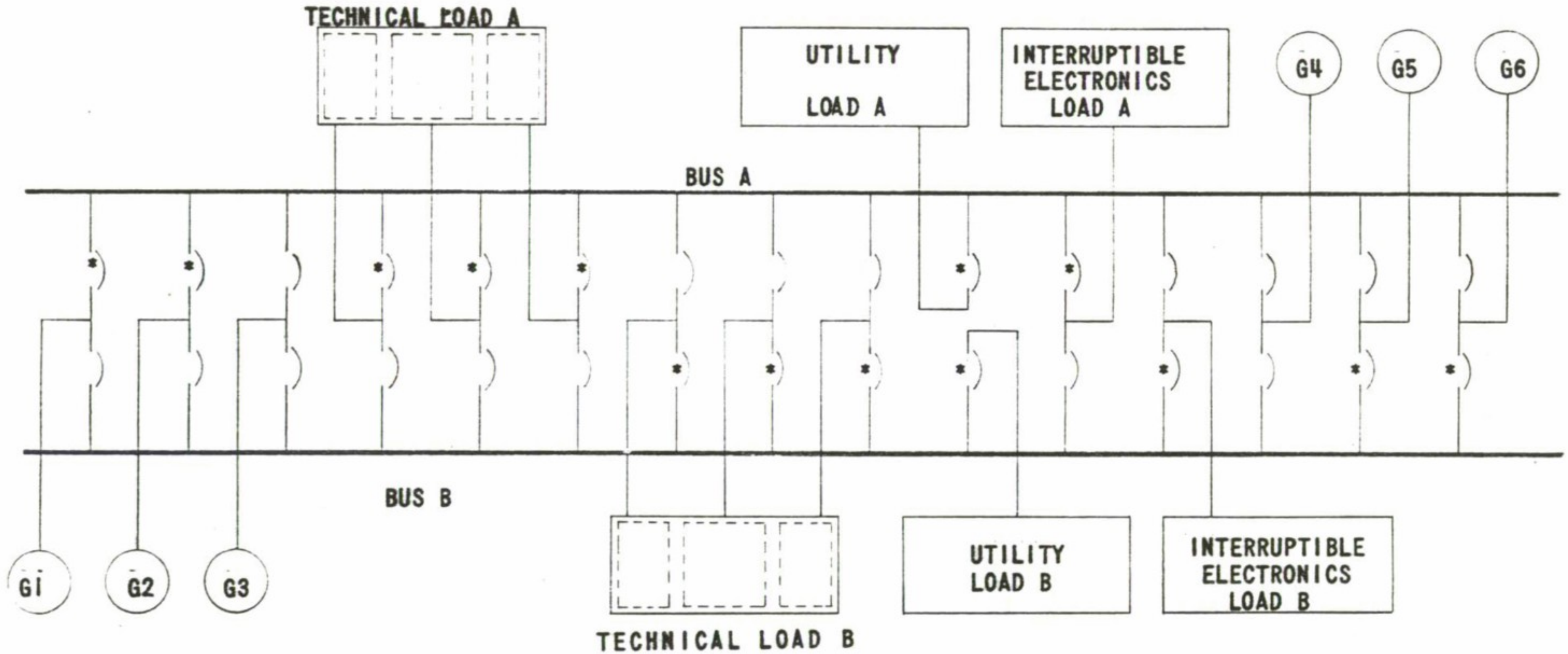


FIGURE 2
ONE LINE POWER DIAGRAM
NON-TRANSFERABLE LOADS
LIMITED GENERATOR TRANSFERABILITY



*INDICATES NORMALLY CLOSED BREAKER
ALL OTHERS ARE NORMALLY OPEN

FIGURE 3
ONE LINE POWER DIAGRAM

ALL GENERATORS TRANSFERABLE

7.0 EXTENTION OF CONCEPTUAL LAYOUT TO MULTIPLE COMMUNICATION COMPLEXES

The communication system described prior to this section implies a one-way transmission type of quadruple-diversity communication. The design philosophy of this and the companion report applies, as well. for a two-way quadruple-diversity communication system and also to stations servicing more than one communication system.

7.1 ONE-WAY TRANSMISSION

An intermediate station within a one-way communication system basically contains four recievers, possibly two transmitter units, and an appropriate number of antennas; one set of antennas for receiving and another set directed in the continuing direction for retransmission. Some type of combining or selection device obtains the optimum output from one, two or more receivers and delivers it to all transmitters for purposes of retransmission. The configuration of such a quadruple-diversity communication system is considered as two dual-diversity units each powered via a separate bus. (In this example, one dual-diversity unit has two receivers and one transmitter.)

At the terminal stations of this one-way communication system there are a set of receivers or a set of transmitters with their associated antennas. Division into two dual-diversity configurations is the same as for the intermediate stations except that less equipment is connected to each bus.

7.2 TWO-WAY COMMUNICATION

A two-way quadruple-diversity system contains two quadruple-diversity complexes - one to accommodate quadruple-diversity communica-

tion in one direction and the other complex for communication in the return direction. Each of these complexes, in turn, contains two dual-diversity units as discussed in the preceding section.

The acceptable approach of supplying power to the communication load is still the same, in that a dual-diversity unit for transmission in one direction, together with a dual-diversity unit for transmission in the return direction, connect to one bus, and the remaining dual-diversity units connect to the other bus.

A station serving more than one communication system for example, may consist of an East-West system link and another system for the North-South link. Again, application of the basic rule requires that one dual-diversity unit in each of the quadruple-diversity complexes connect to one bus while the remaining dual-diversity units connect to the other bus.

7.3 REMOTE RADIO BUILDINGS

At some stations, the communication equipment, other loads, and the power plant are all located within one main building. This arrangement means that the power generation system is essentially in close proximity to the loads.

At other stations, some of the communication and other load equipments may be installed in a second building called the Remote Radio building. Even so, the basic power distribution concept of employing a dual-bus configuration applies. The design merely requires extension of the dual bus over to the Remote building via cables protected by suitable circuit breakers. The distribution at the Remote building is then a repeat or continuation of the dual-bus layout in the main building with the same arrangement of distribution, protection, and transfer for the load.